THE OCCURRENCE OF RADIOLARIA IN PALÆOZOIC ROCKS IN N.S. WALES.

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(Plates xxxvii.-xxxviii.)

CONTENTS.

1. Bibliography.

The first reference known to me as to the occurrence of radiolarian rocks in Australia is in a paper by Dr. G. J. Hinde, F.R.S.*

This rock was obtained by Capt. Moore, of H.M.S. "Penguin," about 1891, from Fanny Bay, Port Darwin. "The rock in question is of a dull white or yellowish white tint, in places stained reddish with ferruginous material; it has an earthy aspect like that of our Lower White Chalk, but it is somewhat harder than chalk, though it can be scratched with the thumb-nail. There are no signs of stratification, and it appears as a fine-grained homogeneous material." Under the microscope the groundmass is seen to be made up of minute granules and mineral fragments, isotropic for the most part, being probably amorphous silica. The minute grains, however, and angular particles polarize: some appear to be quartz, others rutile. The organic structure

* Q.J.G.S. Vol. xliv. No. 194. May 1st, 1893. Dr. G. J. Hinde. Note on a Radiolarian Rock from Fanny Bay, Port Darwin, Australia.

of the granules is only very faintly marked. The orders of Prunoidea, Discoidea and Cyrtoidea are all represented. The geological horizon to which they belong is very probably that of the Desert Sandstone Formation (Upper Cretaceous).

What is probably an equivalent of this rock has been described by the Rev. J. E. Tenison Woods* as follows :—

"What we find whenever a good section is exposed is this—a layer of loose white, or red, decomposed rock or rubble, some 3 or 4 feet thick, lies on the upturned edges of the slates. Above this a layer some 2 feet thick of loamy earth, which has been surface soil. Above this from 14 to 120 feet of magnesite or carbonate of magnesia, more or less impure, with silicates of alumina and iron, and mere traces of lime. Not often is it pure white, for the stains of brown, red and purple, from iron oxide, permeate the whole."

The above statement by the Rev. J. E. Tenison-Woods, as far as can be ascertained, refers to a rock identical with that which has now been proved to be, not a magnesite, but a radiolarian rock.

Reference may here be made to a note by Dr. Hinde† in which he describes a cherty rock from South Australia, which although derived from sponge spicules rather than radiolaria, yet contains globules of opal silica which might easily be mistaken for radiolaria.

The rock described in the note referred to above appears to be of Tertiary age. The specimens were collected by Mr. H. Y. L. Brown at Yorke's Peninsula, near Adelaide. Dr. Hinde states (*op. cit.* p. 115), "The principal feature is the occurrence of detached sponge-spicules which in places are heterogeneously crowded together in the rock. . . . The matrix in which the

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* Report on Geology and Mineralogy of the Northern Territory, South Australia, p. 5. By authority. Adelaide, 1886.

† "Note on Specimens of Cherty Siliceous Rock from South Australia." Geol. Mag. New Series. Dec. iii. Vol. viii. 1891. pp. 115-116.

spicules and quartz grains are imbedded appears to be mainly of amorphous or opal silica, nearly entirely neutral to polarized light between crossed Nicols, and it is principally in the form of very minute globules or discs usually aggregated together so as to exhibit a microscopic botryoidal appearance, the globules or discs varying from ·01 to ·03 mm. in diameter. The globular form of opal silica is similar to that which occurs in many of the sponge-beds of the Upper Greensand in this country, and there can hardly be any doubt that in this Australian Chert it is due, as in the Chert of this country, to the solution and redeposition of the organic silica of the sponge-spicules."

As far as I am aware, the above are the only references to the occurrence of radiolarian rocks in Australia; and in both cases it would appear that the rocks mentioned are of late Mesozoic age.

Before proceeding to describe the horizons where radiolaria have recently been observed by me in Palæozoic rocks in N.S.W., it might be of interest, in view of the grand scale on which the radiolarian rocks are now known to be developed in this colony, and in view also of the fact that some of the literature relating to radiolaria is rather inaccessible to Australian geologists, to briefly summarize the more important works relating to Palæozoic and Mesozoic radiolaria in Extra-Australian areas.

Radiolaria have been described by Dr. D. Rüst* from Mesozoic rocks, the Gault of Zilli, and the Neocomian of Gardenazza. The radiolaria in the best state of preservation were those found in the Cretaceous Coprolite Beds of Zilli, in Saxony. These radiolaria have been admirably figured and described by this observer.

Dunikowski has described perfect forms from the Lower Lias of the Austrian Alps; while Hantken believes that certain siliceous limestones with *Aptycus*, of Upper Jurassic age, in Central Europe are almost entirely formed of radiolaria.

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* Palæontographica. Vol. xxxi. 1885, and *ibidem* Vol. xxxiv. pp. 181-213. Pls. xxii-xxix., 1888, and Vol. xxxviii., 1892.

Gumbell cites them from the St. Cassian beds; and Waters has detected their remains in the Infra-Lias.

Radiolaria have been described by Dr. Geo. J. Hinde and Mr. F. L. Ransome* from Angel Island from Mesozoic (?) rocks.

Radiolaria have been described from Jurassic or older rocks in the coast ranges of California by Fairbanks.†

Radiolaria have been described from Palæozoic rocks by the following:—Shrubsole has recorded them from the Carboniferous rocks of Great Britain.

Dr. G. J. Hinde‡ has described radiolaria from the Llandilo-Caradoc rock at Corstorphane, in the S. of Scotland.

The same author has described radiolaria from Ordovician cherts at Mullion Island, Cornwall, England.§

Perhaps the most important contribution to our knowledge of the Palæozoic radiolaria is that of Dr. Rüst,‖ and, as much of it has an important bearing on the radiolarian rocks of Australia, I take the liberty of making abstracts from it.

In the *phosphorite* from the Petschora in the S. Urals occur well preserved radiolaria in the form of deep black flinty shells, in a bright brown translucent base. Flinty material and iron are present in the phosphatic limestone. In cases the radiolaria are represented by casts only. In the whetstone and adinole radiolaria are badly preserved.

Radiolaria are beautifully preserved as dark black shells in a cryptocrystalline quartz groundmass in the Lydian-stone of Teufelsecke at Lautenthal.

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* The Geology of Angel Island. University of California. Bulletin of the Department of Geology. Vol. i. No. 7, pp. 193-240. Pls. 12-14.

† "Stratigraphy of the Californian Coast Ranges"—Journal of Geology, Chicago. Vol. iii., 1895, p. 415.

‡ Geol. Mag. New Series. Dec. iii. Vol. vii., 1890, p. 144, and Ann. & Mag. Nat. Hist. Ser. 6, Vol. vi. (1890), p. 40.

§ Q.J.G.S. Vol. xlix., 1893, pp. 215-220. Pl. iv.

‖ Palæontographia. Vol. xxxviii., 1891-92. Beiträge zur Kentniss der fossilen Radiolarien aus Gesteinen der Trias und der Palæozoischen Schichten. Von. Dr. Rüst in Hanover.

The red jasper from Sicily contains numberless radiolarian shells, coloured red, in a translucent siliceous groundmass.

Fairly well preserved radiolaria have been found in red jasper of Lower Devonian age.

At Cabrières, in Languedoc, a very hard black siliceous schist of Ordovician age contains radiolaria, mostly in a bad state of preservation. In the phosphorite of Cabrières, however, dark, porous to dense, concretions contain numerous radiolaria.

The following is an analysis of the phosphorite :—

Water	1·08
Lime phosphate	73·65
Silicate alumina	25·27
	100·

The radiolarian shells were black, yellow, or colourless. No sponge spicules were present. In pieces of rock (siliceous shale) from Saxony, poor in radiolaria, fragments of graptolites are numerous.

Black radiolarian fragments have been observed in fairly hard clay shale of Cambrian age. Others occur in flinty pebbles, but not sufficiently well preserved to admit of the species being determined. Fragments of graptolites and graptogonophores were associated.

The fact must be emphasized that it is chiefly in concretions containing phosphoric acid that the radiolaria are best preserved.

It often happens in all flinty rocks, not only Palæozoic but also Mesozoic, that the quartz filling the original hollows of the radiolarian shells shows a radial habit, and has the form of perfect spherulites exhibiting dark fixed interference crosses in polarized light when the objective is rotated.

In most cases the latticed shell has disappeared. Occasionally, however, the pore openings of the shell are preserved, or one sees a dark circle bounding a clear space, with small regularly placed dark indentations on the inner side.

Very often perfect crystals are developed inside and around these little quartz spheres. Generally these are opaque

octahedra of magnetite and clear or dark yellow rhombohedra of calcite. These crystals are seldom observable in the Silurian forms, and are not visible in the Devonian. Very little other organic remains are associated with the radiolaria. Only sponge spicules, belonging to the Hexactinellidæ, are found associated with the radiolaria, sometimes in great numbers.

Isolated examples only of foraminifera are met with in the siliceous limestone of the Muschelkalk. In the Silurian siliceous shales of Langenstriegis, Rehan and Steben fragments of graptolites and gonophores are not infrequent.

Plant remains.—Prickly macrospores occur in the radiolarian rocks of the Jura as well as in the Carboniferous siliceous schists of the Hartz Mts. These were found in great abundance in a Lower Silurian limestone from Koneprus in Bohemia, in which hitherto radiolaria have not been detected.

Another important contribution to the knowledge of Palæozoic radiolaria is that by Hinde and Fox*, from which the following abstracts may be made.

Radiolaria occur at Codden Hill. The Codden Hill beds have a baked appearance, are whitish, buff, or dark grey in colour, and have frequently a chertoid texture, consisting of thick shales and fine-grained grits.

In places in the radiolarian chert wavellite is developed along the joint planes. Sponge spicules are associated with the radiolarian rock. The radiolarian series of the Culm is probably at least 200 ft. in thickness, if the intercalated fine shales be included.

Individual beds usually are from 2-4 inches thick, rarely as much as 1 foot.

The beds are intersected by numerous fine and even joint planes, which have the effect of dividing the rock up into comparatively small rectangular or rhombohedral fragments with smooth flat surfaces.

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* Q.J.G.S. Nov. 1895, Vol. l. G. J. Hinde and Howard Fox. "On a well marked Horizon of Radiolarian Rocks in the Lower Culm Measures of Devon, Cornwall, and West Somerset."

The radiolarian beds are composed of dark to black chert with a hackly fracture. Other portions are dull grey to white, or the rock is made up of alternate light and dark bands, so as to be striped.

In places the rock is platy, siliceous, or mottled white and black. The soft grey to white beds are very rich in radiolaria. They disintegrate in some cases in water into a fine cream-coloured mud.

The soft beds are of much less frequent occurrence than the hard cherts.

The individual radiolarian beds are minutely laminated.

Microscopic character.—Carbonate of lime is conspicuous by its absence. The radiolarian rock generally shows a siliceous ground mass, in some cases clear and transparent, in others dark and turbid from the presence of fine particles of carbonaceous or ferrous minerals, and minute crystal needles of rutile and zircon. The siliceous groundmass shows between crossed Nicols the faint speckled appearance of cryptocrystalline silica, like flint from chalk. When radiolaria are abundant chalcedonic tints prevail. The radiolaria in the rock have been filled with clear nearly transparent silica free from the rutile crystals and from the dark substances disseminated in the groundmass, and either microcrystalline or cryptocrystalline. Within the radiolarian casts the silica is often fibrous radial, and so shows a black cross in polarized light.

The more distinctly crystalline character of the radiolarian casts facilitates their recognition in the rocks with a clear groundmass where in ordinary light they are scarcely visible, but between crossed Nicols they appear as so many circles of speckled or bright light on a nearly dark ground.

Minute casts of rhombohedral crystals are frequently present, probably of calcite or dolomite, sometimes inside the radiolarian casts. A similar occurrence has already been referred to in the Hartz Mountains. Microscopic cubes of iron pyrites are present in some of the rocks.

In some of the harder and more cherty beds very minute bodies like those in the Pre-Cambrian phthanitic quartzite of Brittany are noticeable, ·006 to ·013 mm. There is no evidence to show that these are organic.

Under favourable conditions of light the latticed structure of the radiolarian shells can be distinctly seen in the coarse material resulting from the disintegration of the soft shales in water.

A few minute dentated plates, perhaps radulæ of gasteropods, of dark brownish tinge are associated with the radiolaria. Detrital fragments, except mica flakes, are either wholly wanting or extremely minute, ·03 to ·065 mm. in diameter.

Rarely limestone is associated with the radiolarian rock, and in the limestone are casts of radiolaria in calcite and also of sponge spicules. Entomostraca, crinoids, and *Endothyra* contribute to form limestones near this radiolarian horizon.

In the majority of the Culm siliceous rocks the radiolaria are now in the condition of solid casts of the original forms; their skeletal walls have entirely disappeared, and the individual casts are only bounded by the siliceous matrix of the rock, and are without definite even outlines. In such instances only the size and general form *with the radial spines* can be distinguished.

In some cases the tests have been naturally stained a brown or amber tint, and in such cases the latticed character of the shell is quite visible.

Mr. Fox in a later paper* thus summarizes the evidence :—"These radiolarian rocks of Cornwall may be compared with similar rocks of S. Scotland and with those described by Rüst from the Hartz, as well as those from the coast ranges of California, of Jurassic age or older. . . . It is evident from these examples that in the process of the formation of chert the finer structures and the more delicate forms of the microscopic organisms disappear nearly entirely, so that it is but rarely that traces of them are now to be seen in the older cherts."

* "The Radiolarian Cherts of Cornwall." Trans. Roy. Geol. Soc. Corn. read Nov. 8, 1895.

2. Localities and Geological Horizons of Radiolarian Rocks in New South Wales.

With the exception of the opal rocks which contain numerous spherical casts, possibly of radiolaria, all radiolarian rocks at present known in N.S. Wales are of Palæozoic age. Radiolarian rocks have so far been discovered by me in N.S. Wales at four different localities—(1) Bingera, (2) Barraba, (3) Tamworth, (4) Jenolan Caves. (See Map, Plate XL., fig. 3.)

Devonian. (?)—(1) Bingera and (2) Barraba. In my Address* to this Society in 1894, I stated "in the New England District of N.S. Wales possibly the red jasperoid shales of the Nundle and Bingera Districts with the associated serpentines may represent altered abysmal deposits, as has been suggested by Captain Hutton for similar rocks in the Maitai Series of New Zealand, unless the red claystone represents rock locally metamorphosed where in contact with the serpentines."

Since reading the above Address, as opportunity offered, I have from time to time studied the red jaspers of Barraba and Bingera, by means of microscope sections. These revealed the presence of numerous spherical bodies composed of translucent chalcedony, distributed through an opaque groundmass of red jasperoid material. It appeared probable that these were internal casts of radiolaria, but the evidence was inconclusive. Last January, through the kindness of Mr. J. J. H. Teall, F.R.S., I was allowed to examine his carefully prepared microscopic sections of the Lower Silurian radiolarian cherts from Mullion Island, off Cornwall, and from the Culm of Devonshire, as well as sections of red radiolarian jasper from the Antarctic regions. It was at once obvious that the last mentioned rock in particular closely resembled the Bingera and Barraba red jaspers. On my return to Sydney, last March, with the help of the third year University students, I resumed my examination of the New England red jaspers. Dr.

* P.L.S.N.S.W. Ser. 2, Vol. viii. p. 594.

G. J. Hinde had placed at my disposal, on leaving England, a valuable collection of British Palæozoic radiolarian rocks, which proved of the utmost use for purposes of comparison. A large number of sections of the red jasper proved conclusively that radiolarian rocks were developed on a large scale both at Barraba and Bingera. It is the opinion of Mr. E. F. Pittman, the Government Geologist, that the red colour of the jaspers was the original colour of the beds at the time of their deposition and that it is not due simply to contact metamorphism. A collection of specimens kindly made for me by Mr. Pittman confirms this theory. The question as to whether these red jaspers are altered "red clays" of deep sea origin will be discussed later. The geological horizon of the red jasper may be provisionally placed somewhere in the Devonian System, perhaps in the Middle Devonian, homotaxial with the Burdekin formation of Queensland.

Lepidodendron Australe occurs in some quantity in rocks which seem to be somewhat newer than the radiolarian beds; but it appears to be represented sparingly, almost, if not quite, as low down as the horizon of the radiolarian rock. This, however, is not yet an established fact.

(3) Tamworth.—Traced southwards, the radiolarian beds have recently been found by me to attain a remarkable development in the neighbourhood of Tamworth. They there consist of siliceous, dark bluish-grey, calcareous rocks, fine-grained blackish-grey claystones and cherts, and coralline siliceous limestone. The coralline limestone beds, of which there appear to be at least two, are from 100 to 1000 ft. in thickness, and are composed chiefly of the following fossils:—*Stromatopora*, *Cyathophyllum*, *Diphyphyllum Porteri*, *Cystiphyllum*, *Favosites gothlandica*, and *F. grandipora* or *Pachypora* (the latter very abundant and characteristic), *Alveolites* (also very abundant), and *Heliolites*.

Mr. Donald A. Porter, of Tamworth, conducted me to the spots where these limestones can be studied to best advantage, and he concurs with me in my provisional deductions with regard to the Tamworth rocks.

The limestones have been considerably altered by contact with the New England granite. The claystones and cherty rocks both above and below the limestones have also been much altered by innumerable granite sills for a zone over five miles in width, measured at right angles to the junction line between the sedimentary rocks and the granite. A lamination, coincident with the planes of bedding, has been superinduced in the claystones. The sills vary from a fraction of an inch up to several feet in thickness, and at first sight had every appearance of being regularly interstratified with the sediments. A careful examination, however, at once revealed their intrusive character, as they trespass slightly across the planes of bedding and have slightly altered by indurating and developing chiastolitic minerals, the sedimentary rocks both above and below them. The claystones and cherts dip chiefly westwards at angles of from 45 to 60°. At Tamworth Common the dip is W. 20° S. at 52°. Radiolaria are abundantly distributed through these claystones and cherts in the form of chalcedonic casts. Associated with the claystones is the siliceous calcareous rock previously referred to. A good section shewing it *in situ* is exposed at the quarries on the Tamworth Temporary Common. The chief bed is about 18 inches in thickness. It weathers superficially into a soft brown friable rock of the colour of Fuller's earth, much resembling bath-brick. Fresh fractures, of unweathered portions, shew the rock to be bluish-grey and compact. If a surface of the unweathered portion be smoothed and polished and then etched with dilute hydrochloric or acetic acid, interstitial carbonate of lime is dissolved out, and well preserved siliceous shells of radiolaria become visible. These will be described in detail later. A second bed of siliceous radiolarian limestone occurs at a point about a mile easterly from the preceding. It is a few inches only in thickness. For the general appearance of this rock see Plate XXXVII. The radiolarian rocks are probably at least 2000 feet thick at Tamworth. The distance from Bingera on the north to Tamworth on the south is 85 miles. Barraba, intermediate between these two places, is 34 miles south of Bingera and 51 miles north of Tamworth. The

radiolarian rock is almost certainly continuous from Bingera to Tamworth.

(4) Jenolan Caves.—This locality is about 200 miles south by west from Tamworth. The rocks developed in this neighbourhood are the Cave Limestone, thin grey argillites and dark grey and reddish-purple shales and black cherts with numerous dykes and sills of quartz-felsite, and basic dykes rendered porphyritic by augite. The Cave Limestone is a somewhat massive rock from 380 to 420 feet in thickness. Stratification is well marked at its upper surface. It dips W. 10° S. at 60° as shown by me this year in my Address to the Royal Society of N.S. Wales, Plate II.

The following fossils have been recorded as occurring in it by Mr. R. Etheridge, junr.* :— *Pentamerus Knightii*, J. Sowerby; *Palæoniso Brazieri*, Eth. fil.; *Loxonema antiqua*, De Kon., and a large *Favosites*.

Mr. Etheridge considers that the occurrence of the large varieties of *Pentamerus Knightii* in this Cave Limestone renders it not improbable that it approximates in age to the Aymestry Limestone of England. At the same time he comments on the fact that *Pentamerus Knightii* has not yet been discovered in the Yass beds of N.S. Wales, the horizon of which is almost certainly Upper Silurian, and *Mucophyllum crateroides*, a very characteristic and abundant coral in the Yass beds has not yet been observed in the Jenolan Cave Limestone. *Stromatopora*, on the other hand, is very abundant, as it is in the Tamworth Limestone. On the whole, I am of opinion that the Jenolan Cave Limestones and their associated radiolarian beds are somewhat newer than the Yass beds, so that if the Yass beds are Upper Silurian, the Jenolan Cave Limestones may be of Lower or Middle Devonian Age. Immediately overlying the limestone are fine-grained dark clay shales and argillites and black cherts. Mr. Voss Wiburd, the guide to the caves, informs me that these must be at least

* Records Geol. Surv. N.S. Wales. Vol. iii. Part ii. 1892, p. 57, and Annual Report Dep. Mines, N.S. Wales, 1893, p. 128. By authority. Sydney, 1894.

1000 feet in thickness. They are capped by basalt. Near their junction with the limestone they are seen to be very much intersected by eruptive dykes, porphyritic by augite. It may be inferred from the circumstance that nearly all the dykes to the east of the limestone are felsitic, while no felsite dykes occur to the west of the limestone, that the basic character of the former group of dykes is due to the eruptive rock having assimilated much lime in its passage through the limestone bed, for as the dip of the limestone is westerly at an angle of 60°. and the dykes are nearly vertical, they could not have reached the surface without first passing through the limestone bed. The dark shales are not distinctly cherty except where they are in close proximity to the dykes. The cherty character of the beds in this case is due therefore, I think, to contact metamorphism rather than to silica derived from radiolarian shells. Both the black cherts and the softer and less siliceous dark grey shales abound in casts of radiolaria. The casts are in the best state of preservation in the cherty bands. Below the Jenolan Cave Limestone are several hundred feet of dark indurated shales, greenish-grey argillites, reddish-purple shale and coarse volcanic agglomerates with large lumps of *Favosites*, *Heliolites*, &c. The argillites and grey shales contain numerous casts of radiolaria, but in a very bad state of preservation.

3. Macroscopic and Microscopic Description of the Radiolarian Rocks.

The radiolarian rocks from Bingera and Barraba are hard red jaspers, the base of which is very opaque even in thin section. In places the red jaspers pass into a nearly white quartzite. Such portions of the rock as approach quartzite and chalcedony in character show scarcely any trace of radiolaria, probably owing to the shells having been completely dissolved during the metamorphism of the rock. The opaque red jaspers, however, especially those which have not undergone much metamorphism, contain very abundant casts of radiolaria, so abundant as to make it

evident that the radiolaria must in this case have contributed very largely to form the rock.

Under the microscope numerous spherical or oval bodies, from ·05 mm. to ·215 mm. in diameter, are seen to be distributed through the base. The outlines of the larger casts are jagged, the projecting points representing casts in chalcedony of the openings in the original latticed shell. Most of the smaller casts are probably those of the medullary shell. The larger casts very frequently occur in pairs. Only in one instance was the original outer shell of a radiolarian organism noticed. It was separated by an inner ring of red jasper from the cast of the medullary shell. The form appeared to be allied to *Carposphæra*. Some of the largest of the casts, about ·215 mm. in diameter, are probably referable to *Cenosphæra*. Many of the radiolarian casts have participated in the numerous minute faults to which the rock has been subjected. The Tamworth radiolarian rocks, as already mentioned, are partly thin siliceous limestones, partly argillites and black cherts, partly massive coralline limestones.

The black cherts do not appear to owe their silica entirely to the radiolaria, but to have derived it largely from the thousands of granitic sills with which they are so regularly intersected as to give the appearance of interstratification.

The casts of radiolaria in these cherty argillites are much better preserved than those in the red jaspers, and also than those in the black cherts of Jenolan.

Many of them show distinct traces of the latticed structure of the shell. The radiolaria, however, are in a far better state of preservation in the thin siliceous limestones, which weather into a kind of "rottenstone." On the weathered surface of this rock the radiolaria can be very easily distinguished with a pocket lens. Thin sections of the rock do not show much of the structure of the shells under the microscope on account of the difference in the respective refractive indices of quartz and calcite being insufficient to show up plainly the structure of the radiolarian shells. The best results were obtained by thinning slices of the rock to the thickness of the full diameter of the larger radiolarian shells, and

then etching the slice with dilute hydrochloric acid. Much of the structure can be developed in this way as shown on Plate XXXVII., from a microphotograph kindly taken for me by Mr. W. F. Smeeth, M.A., B.E., Assoc. R.S.M.

As I have forwarded some of this material to Dr. Hinde, who has kindly undertaken to describe the radiolaria specially, I will not attempt to do more than mention that some of the commonest forms in the Tamworth rock are figured on Plate XXXVIII.

It is obvious that the legion of the Spumellaria is much better represented than that of the Nassellaria. Fig. 7, Plate XXXVIII. appears to represent a *Xiphosphæra*, but the spines appear to be perforated by openings, giving the shell somewhat the appearance of *Pipettetella* (Challenger Reports, Radiolaria, Vol. xviii. Pl. 39, Fig. 6). Fig. 2 shows the inner and outer shells fairly well preserved, and is probably a *Haliomma*. Fig. 5 perhaps represents a *Theodiscus;* and Fig. 9 perhaps a *Staurolonche* or an *Astromma*.

As regards the state of preservation of the shells the original siliceous skeleton is for the most part represented, but is sometimes replaced by iron pyrites. Often internal casts alone, in chalcedony, are all that remain to tell of the former presence of the radiolaria. Spicules of hexactinellid sponges are visible in places, in this rock. The radiolaria are so abundant as to give this rock, when etched, the appearance of a Barbadoes earth. It was probably in its original condition a radiolarian ooze.

At the Jenolan Caves, as already stated, the radiolarian casts are best preserved in the black cherts, where they are very numerous. Numerous traces of radiolaria can also be detected in the soft argillites and hardened clay shales.

The radiolarian casts are in a better state of preservation in the black cherts than in the red jaspers of Barraba and Bingera. Latticed structure is, however, scarcely anywhere to be seen. Such slight traces of it as do occur are preserved in the form of opaque black fragments of network entangled in a sub-translucent cryptocrystalline base, as seen in thin sections under the microscope.

Casts of the inner and outer shells are well preserved in the form of a nucleus of translucent chalcedony separated by a zone of the grey base from an outer ring of clear chalcedony.

Radial spines are indistinctly visible in many of the specimens, and can be seen best under crossed Nicols. Most of the casts are spherical, and vary in diameter from ·05 mm. to ·2 mm.

Internal casts of the medullary shell are more frequent than casts of the outer shell.

Sponge spicules were not observed.

4. Summary.

The radiolarian rocks, as yet discovered in New South Wales, range for at least 285 miles, from the Jenolan Caves on the south to Bingera on the north. Their total thickness has not yet been ascertained, but at Tamworth it appears to amount to at least 2,000 feet, and at Jenolan to not less than 1,000 feet. The radiolarian rocks consist of red jaspers, black cherts, thin siliceous limestones, and thin bedded argillites. The radiolaria hitherto discovered are in the best state of preservation when enclosed in the siliceous limestone. For the most part, however, they are represented merely by chalcedonic casts, the casts of the medullary shell being more frequently preserved than those of the outer shell. In the thin siliceous limestones of Tamworth the radiolarian shells frequently have the original substance of the skeleton fairly well preserved in the form of sub-translucent to translucent silica. Rarely the original siliceous skeleton is found to be replaced by iron pyrites. In the Jenolan Cave Cherts the radiolarian skeletons show obscure traces of latticing in the form of fragments of opaque black nets.

At Tamworth and Jenolan the radiolarian rocks have beds of coralline limestone interstratified with them, probably over 1,000 feet thick at the former, and over 400 feet thick at the latter locality.

At the Jenolan Caves a volcanic agglomerate containing blocks of coral is associated with the radiolarian shales.

The associated fossils prove the radiolarian rocks, at Tamworth at all events, to be homotaxial with the Burdekin Formation of Queensland. Mr. R. L. Jack, the Government Geologist of Queensland, and Mr. R. Etheridge, Junr., consider the age of the Burdekin beds to be Middle Devonian.

5. Deductions.

(i.) In New South Wales there is a great development of rocks, chiefly argillites, cherts and jaspers, formerly considered to be unfossiliferous, but now proved to be formed largely of the shells of marine organisms, the radiolaria.

(ii.) The geological horizon of these rocks is probably Middle or Lower Devonian, perhaps Siluro-Devonian.

(iii.) The cherty character of some of the rocks containing the radiolarian casts is due rather to the introduction of silica secondarily from eruptive dykes and sills than to the silica contained in the radiolarian shells.

(iv.) The preservation of the radiolarian casts in the black cherts is chiefly due to the silicification and induration superinduced by contact metamorphism.

(v.) This contact metamorphism took place some time between the close of the Carboniferous Period and the commencement of the Permo-Carboniferous Period, and was the result of the intrusion of sills and dykes of granite.

(vi.) (*a*) The presence of thick beds of coralline limestone interstratified with the radiolarian rocks, and (*b*) the vast thickness of the radiolarian beds (several thousand feet being formed within a single epoch of one period of geological time) render it improbable that the rocks were formed in very deep seas. This agrees with Professor Sollas' recent observations on the 'Soapstone' of Fiji, considered by Brady to be of deep sea origin, but now proved to have been deposited in shallow water. At the same time the absence of conglomerates (with the exception of the volcanic agglomerate at Jenolan) from the radiolarian beds and the abundance of interstratified limestone indicates deposition in tranquil water at some distance from the shore.

(vii.) The red jaspers of Barraba and Bingera may possibly be of deep sea origin, and represent consolidated "red clays," but this is not as yet proved.

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EXPLANATION OF PLATES.

Plate xxxvii.

Surface of calcareous radiolarian rock, etched with dilute HCl., showing how largely the rock is made up of radiolarian shells, many of which exhibit latticed structure and radial spines. × 50.

Plate xxxviii.

Fig. 1.—× 200. Radiolarian shell of sub-translucent silica. Form somewhat resembling *Heliosoma* (?). Tamworth.

Fig. 2.—× 200. Radiolarian shell of sub-translucent silica. Resembling *Haliomma*.

Fig. 3.—× 200. ,, ,, ,, ,, Genus not determined.

Fig. 4.—Radiolarian shell of sub-translucent silica. Genus not determined.

Fig. 5.— ,, ,, ,, ,, Possibly *Theodiscus*.

Fig. 6.— ,, ,, ,, ,, Genus not determined.

Fig. 7.— ,, ,, ,, ,, Probably *Xiphosphæra*.

Fig. 8.— ,, ,, ,, ,, Genus not determined.

Fig. 9.— ,, ,, ,, ,, *Staurolonche* (?) or *Astromma* (?).

Fig. 10.—Radiolarian shell of sub-translucent silica, showing how the medullary shell outlasts the outer shell. Tamworth.